LCA Methodology

A Life Cycle Method for Assessment of a Colliery's Eco-indicator

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Abstract

Global Scope and Background. The study was aimed at presenting the methodology of the process eco-indicator, in relation to hard coal mines, and thereby making evaluation of the impact of the mine's coal extraction process on the environment. The life cycle of a mine is made up of three phases: opening and developing the mine's deposit, extraction of the mine's deposit, closing the mine.

Methods. The assessment of environmental influence of mining operation of a colliery was executed on a basis of the life cycle analysis, in accordance with the standard series PN-EN 14040. The environmental loads caused by individual unit processes were calculated by means of the aforementioned methodology with division into the basic influence categories: human health, ecosystem quality and natural resources. The obtained values of eco-indicators for the individual unit processes made it possible to compare the unit-process-caused environmental loads. Mean values of the eco-indicators of the individual unit processes were calculated by means of the inventory analysis covering 38 collieries. Next, these indicators were used to compare environmental load values by each similar process in a colliery. A total eco-indicator was calculated for colliery by summing up the eco-indicators of the individual unit processes. The eco-indicators, structured as above, were calculated for the phase of opening out a deposit and for the phase of extraction.

Results and Discussion. The model mine in the phase of extraction of a deposit causes a total environmental load which expressed in points of the eco-indicator 99 amounts to 23.9 [MEw]. In the 'human health' category losses amount to 8.4 per cent, in the 'quality of ecosystem' 0.6 per cent and in the 'resourses' category 91 per cent.
The greatest losses in all categories are caused by the process of getting body of coal and the next greatest ones are:

- In the 'human health' category – cleaning coal at a preparation plant (250.0 kEw),
- In the 'quality of ecosystem' category – cleaning coal at a preparation plant (25.0 kEw),
- In the 'resources' category – entry driving by means of explosives (745.7 kEw).

Value of the eco-indicator 99 per 1 Mg (tonne) of coal extracted at the model mine amounts to 9.55 Ew.
On a basis of this methodology, calculations of the value of the eco-indicator 99 were performed for a real working colliery (extraction of 1.23 million tonnes in 2001). An inventory of characteristic quantities of individual unit processes connected with the extraction of this colliery was prepared. The total environmental load of this mine was 11.14 MEw (in the 'human health' category losses amounted to 7.9 per cent, in the 'quality of ecosystem' category 0.5 per cent, and in the resources' category 91.6 per cent).
The greatest losses in all categories were caused by the process of getting body of coal which amounted to 10.8 MEw, and next the process of driving a heading by means of heading machine which amounted to 130.9 kEw.
The value of the eco-indicator 99 for 1 Mg (tonne) of coal extracted in 2001 at the above-mentioned mine amounts to **9.06 Ew** and is lower than the value of the eco-indicator 99 calculated for the model mine.

Conclusion. By means of the presented methodology it is possible to calculate environmental loads caused by individual unit processes with division into the basic categories of influence: human health, quality of ecosystem and natural resources. The calculated values of the eco-indicators of the individual unit processes enable to make comparisons of environmental loads and eventual decision making on changes in the ecological policy of a mine.

Recommendation and Perspective (Outlook). The presented LCA methodology can be used to compare the operation of individual mines in the aspect of their influence on the environment. If the data of the same type with regard to unit processes are at disposal, then the mines can be ranked. Based on the LCA's results, it is possible to make capital decisions connected with modernisation of specific production processes.

Keywords: Coal mine; data collection; eco-indicator; impact assessment; life cycle assessment (LCA); life cycle impact analysis (LCIA); process development; methodology, coal extraction

Introduction

Mining operation includes numerous activities and actions connected with exploration, identification, opening out, development, extraction and preparation of hard coal, but also utilisation of the wastes coming into being in this process. The character of this operation, its specificity influences the human environment and the influence causes negative effects. Hard coal is the main energy resourse in Poland and according to the actual policy of the Polish Government it will remain to be one until 2020. Thus it is indispensable to focus on activities aimed at minimisation of the negative environmental effects caused by collieries. A foundation for these activities should be a detailed balance to assess effects a colliery causes in its environment, most appropriately in a measurable form-numerical. In this study an assessment of influence of a colliery's mining operation on environment based on life cycle analysis in accordance with the standard PN-EN 14 040 was presented [1]. By means of this methodology environmental loads resulting from individual unit

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processes were calculated in the form of the eco-indicator 99 [2]. As mentioned before the subject of the considerations in this study is a colliery.

The life cycle of a mine is made up of three phases:
- Opening and developing the mine's deposit,
- Extraction of the mine's deposit,
- Closing the mine.

Size and complexity of the production system of a mine causes a need of carrying out a preliminary analysis of all processes and their selection from the point of view of life cycle analysis (LCA).

The processes selected for the further analysis were divided, according to the criterion of their influence area and their character, into three groups:

- Basic local processes, characterised by direct connection with the basic hard coal production link; their assignment to a specific place at a colliery constitutes another characteristic of these processes,
- Basic decomposed processes, also connected with the basic hard coal production link but they cannot be assigned to a specific place at a colliery because they are decomposed and have an effect on the whole system of a colliery,
- Auxiliary processes which are not connected with the basic hard coal production link and only fulfil supporting functions towards the production process.

In each group there were identified separable partial processes which are the so-called unit processes. Such an approach makes it possible to prepare a colliery model in the form of a production system in which the necessary media flow to its mining workings. In turn the waste media and mined coal form the mining workings flow back to the minehead.

1 Colliery as a Network of Interconnected Unit Processes

Depiction of a colliery as a production system shows connections between individual processes that are important in further analyses [3]. An example for such interdependence are unit processes like 'mining the body of coal' and 'haulage of the gotten'. With the object of presenting a colliery as a hard coal production system models were prepared that take into account the unit processes and their interconnections. These models were independently prepared for each phase of a colliery's life cycle, simultaneously taking into account the categories of influence of each of the unit processes on the environment.

1.1 Unit processes in the phase of opening out and development of a deposit

The opening-out and development phase ranges over the period of time from the beginning of field activities to the moment of winning a first tonne of hard coal from a longwall face. Duration of this phase depends on geological and mining conditions and usually amounts to not more than several years. This phase includes following mining activities:

- Preparation of a colliery's minefield,
- Sinking a shaft (shafts),
- Opening-out work – preparation of the skeleton of opening-out headings, that is to say, a network of stone drifts and cross headings until the coal seam to be extracted is reached,
- Development activities – panelling an opened-out seam with flat and inclined coal entries,
- Preparation of haulage infrastructure for extracting coal, that is to say putting into service wheel and conveyor haulage,
- Longwall face installation.

Diagram showing unit processes in the phase of opening out and development of a deposit is presented in **Fig. 1**.

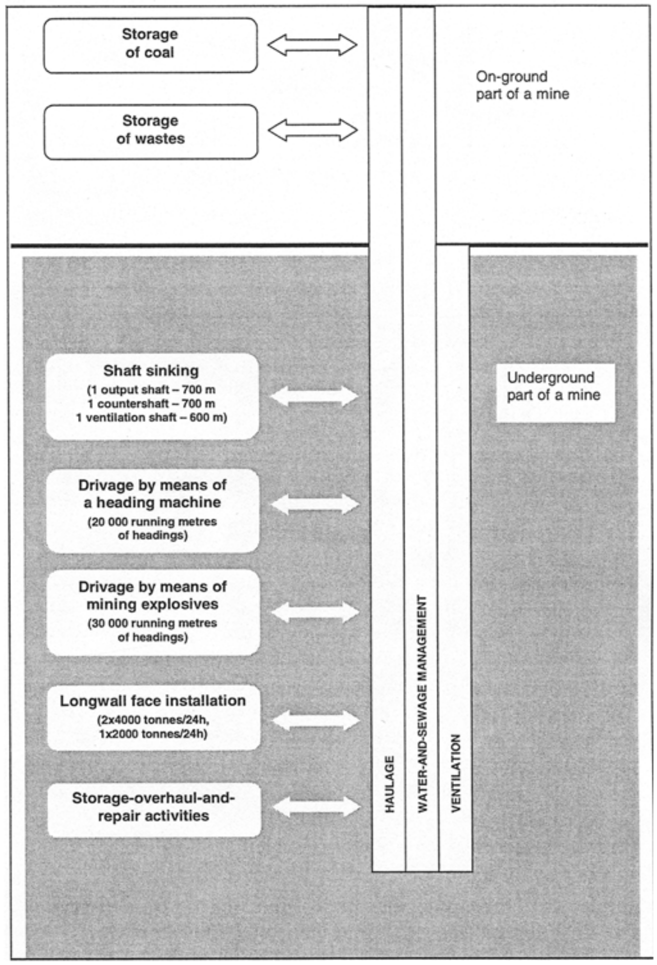

Fig. 1: The model presenting a colliery as a production system in the phase of opening out and development of a deposit

1.2 Unit processes in the phase of extraction of a deposit

Gaining a first tonne of coal from a longwall face means beginning the phase of extraction of a deposit that lasts until coal extraction process in the last longwall face of the colliery under consideration is closed. The phase of extraction of a deposit in terms of the whole mine lasts usually a few dozen years. The great importance of this phase in the ecological influence analysis derives from the large scale of the resources' stream used as input into the production process as well as from the large scale of the output's stream and the wastes' stream. Within duration of the phase new extraction panels are developed and extracted panels are closed, in parallel. These activities are aimed at maintaining appropriate production capacity of a mine in accordance with assumed technical and economic guidelines. The investment in development of a working field or a new extraction level

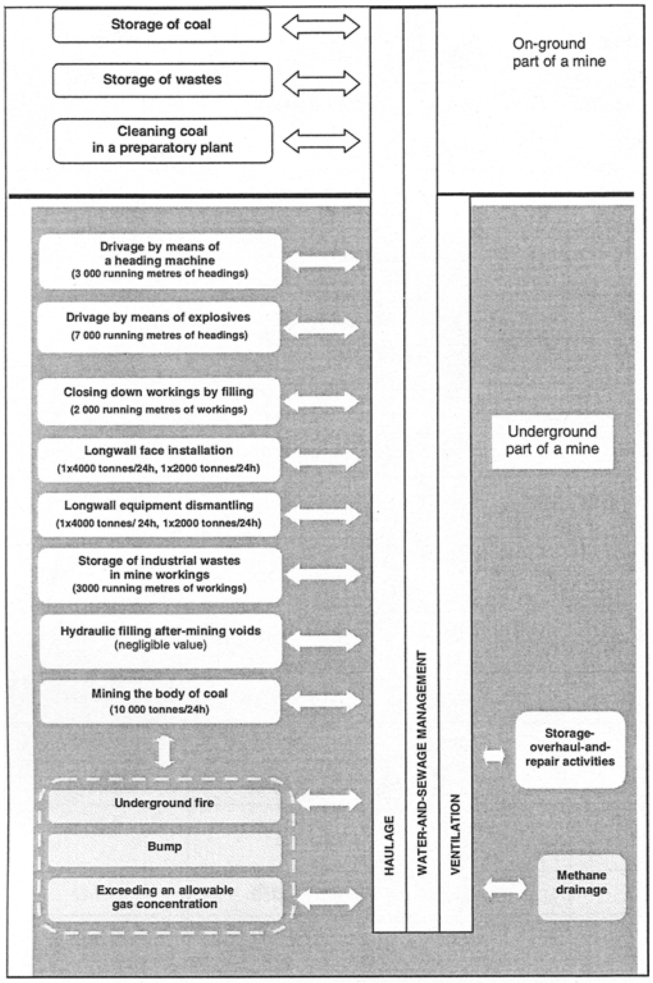

Fig. 2: The model of a colliery as a production system in the phase of extraction

lasts several years, therefore all indispensable decisions are made a long term in advance. Development of a new working field significantly increases the scale of mining work. All these activities are transposed on a large number of unit processes run at a mine simultaneously.

The diagram representing unit processes in the phase of extraction of a deposit is shown in **Fig. 2**. The production system of a colliery within this phase causes a significant number of negative influences on the environment. In the analysis of these influences both on-ground and underground parts are taken into account.

1.3. Unit processes in the phase of closing down a mine

The phase of closing down a mine encompasses operations which should result in entire physical closing down of all workings within the minefield of a colliery. This phase begins at the moment of an end of extraction of coal from working faces. With the object of gaining such a result workings are successively stopped or filled. Taking into account the categories of ecological influences this phase is connected with rather a great hazard for human life and health, therefore the 'Human Health' category needs a detailed analysis here. The importance of other categories of influence is limited because of minor scope of activities which dismantling work used to encompass. A diagram presenting the unit processes in this phase of a colliery's life is shown in **Fig. 3**.

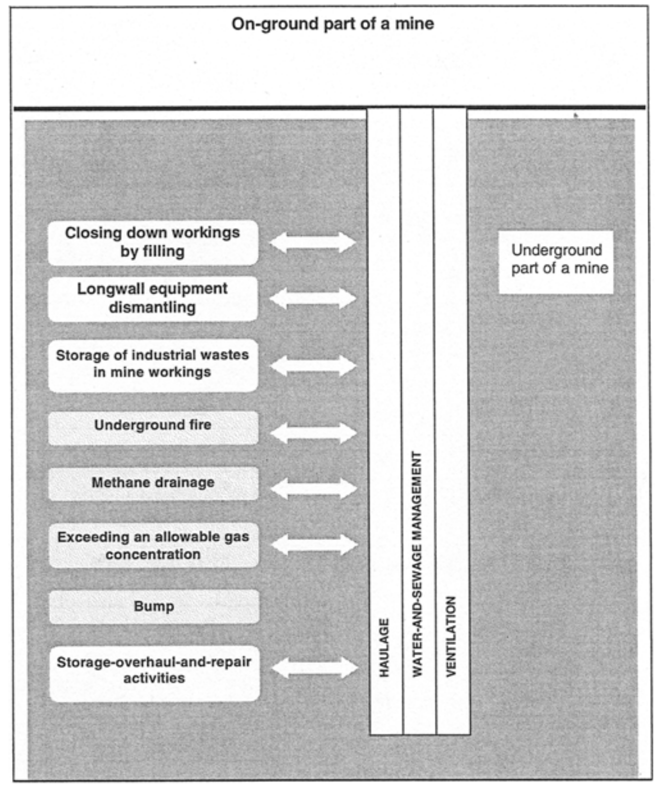

Fig. 3: The model of a colliery as a production system in the phase of closing down the colliery

2 Methodology of Calculating Eco-indicators

Data indispensable to calculate eco-indicators were prepared during the inventory analysis of unit processes. The analysis presented energy and materials flows in the course of transformation of input elements into output elements in a quantitative form. The inventory analysis ranged over 38 collieries [3].

On the basis of the analysis data were gained which are necessary to calculate eco-indicators of individual unit processes.

With the object of calculation of final values of the eco-indicator 99 originating from individual unit processes at a colliery following activities were performed:

- Life trees of processes were worked out,
- An inventory of input and output data was drawn up,
- A unit value of the eco-indicator 99 of each process was calculated,
- An environmental load analysis within individual categories of loss was performed (human health, quality of an ecosystem and resourses),
- The total environmental load connected with processes recorded in the inventory was calculated,
- The mean value of the eco-indicator 99 was calculated for each unit process.

Table 1: Mean values of the eco-indicator 99 for identified unit processes

No	Process name	Unit	Eco-indicator in individual categories			Eco-indicator [Ew]
			Human health	Ecosystem quality	Resource use	
1	Shaft sinking	Mg of mined rock	9.91	2.57	7.13	19.61
		m^3 of driven shafts	30.56	7.92	22.05	60.53
2	Drivage by means of blasting	m^3 of headings	1.16	0.24	7.45	8.85
		Mg of mined rock	0.72	0.15	4.59	5.46
3	Drivage by means of a heading machine	m^3 of headings	1.40	0.22	2.22	3.84
		Mg of mined rock	1.68	0.26	2.68	4.62
4	Getting the body of coal	Mg of gotten	0.60	0.03	8.18	8.74
5	Longwall face installation	m^3 of starting faces	1.04	0.25	0.69	1.97
6	Longwall equipment dismantling	m^3 of longwall faces	0.07	0.04	0.12	0.22
7	Hydraulic backfilling after-mining voids	m^3 of goaf voids	0.43	0.37	0.95	1.74
8	Pneumatic stowing after-mining voids	m^3 of goaf voids	0.27	0.01	0.07	0.35
9	Closing down workings by filling	m^3 of workings	0.43	0.35	0.93	1.71
10	Storage of industrial wastes in workings	Mg of stored wastes	0.016	0.002	0.191	0.208
		m^3 of workings	0.0006	0.0001	0.0067	0.0074
11	Coal cleaning at a preparation plant	Mg of cleaned coal	0.10	0.01	0.14	0.251
12	Storage of coal	Mg of stored coal	0.060	0.007	0.079	0.147
13	Storage of wastes on the ground	Mg of stored wastes	0.063	0.008	0.082	0.153
14	Methane drainage	m^3 of methane	0.0856	0.00022	0.0029	0.0881
15	Bump	MJ	2 348	637	1 623	4 607
16	Storage-overhaul-and-repair activities	1 month	355.25	65.75	447.50	868.5

For each process a unit mean value of the eco-indicator 99 was calculated, i.e. a value that corresponds to the measure unit of a process (1 Mg, 1m^3, 1 month, 1 MJ). Results are presented in **Table 1**. Then the results were utilised in the environmental load analysis of the model colliery.

The model was verified by calculations made for a real mine.

3 Assumptions for the Quantitative Model of a Colliery for the Needs of Eco- indicator

Parameters necessary for calculations were identified based on examinations carried out on a representative sample of 38 collieries (**Table 2**).

Assumptions:

1. The quantitative model was prepared for collieries with output of 2.5 million tonnes of commercial coal (net quantity per year).
2. Two phases were taken into account: the phase of opening out and development of a deposit, and the phase of extraction of a deposit. Right restitution of the working capacity was assumed in the extraction phase (which means refraining from driving main opening-out headings).

Parameters of the model in the phase of opening out and development of a deposit:

1. Final depths of shafts:
   - 1 output shaft – 1–700 m,
   - 1 countershaft – 1–700 m,
   - 1 ventilation shaft – 1–600 m.
2. Longwall face installation (2 longwalls rated at 4 000-tonne output per day and night, and 1 longwall rated at 2 000-tonne output per day and night),
3. Length of headings driven by means of explosives – 30 000 running metres,
4. Length of headings driven by means of heading machines – 20 000 running metres.

Table 2: Parameters of the model mine

Parameter	For the group of 38 mines	Mean for one mine	Values assumed in calculations
Output per day and night [tonnes/24h]	368,000	9,684.21	10,000
Output per year [million tonnes/year]	97.52	2.56	2.50
Total number of shafts	239	6.29	3
Output shafts	59	1.55	1
Ventilation shafts	95	2.50	1
Countershafts	85	2.24	1
Number of extraction levels under operation	74	1.96	1
Length of opening-out and development headings under operation [m]	4,624,341	121,693	50,000
Development work intensity ratio [running m/1000 tonnes]	4.1	4.1	4.1
Mean extraction depth [m]	584	584	650

Parameters of the model in the phase of extraction of a deposit:

1. Longwall face installation (1 longwall rated at 4 000-tonne output per day and night, and 1 longwall rated at 2 000-tonne output per day and night),
2. Mining body of coal (2 longwalls rated at 4 000-tonne output per day and night, and 1 longwall rated at 2 000-tonne output per day and night),
3. Longwall face installation (1 longwall rated at 4 000-tonne output per day and night, and 1 longwall rated at 2 000-tonne output per day and night),
4. Length of headings driven by means of explosives – 7 000 running metres,
5. Length of headings driven by means of heading machines – 3 000 running metres,
6. Closing down workings by filling with industrial wastes (3 000 running metres – this process is more intensive in the case of closing down a part of the mine),
7. Closing down workings by mine filling (2 000 running metres – this process is more intensive in the case of closing down a part of the mine),
8. Storage of coal – 200–300 thousand tonnes per year,
9. Storage of wastes – output: 1.3 million tonnes per year, including 500 thousand tonnes per year (mine run was assumed to have 35 % of pollution).

4 Eco-indicator of the Model Mine in the Phase of Opening out and Development of a Deposit

With the object of evaluating the scale of influence of a mine on the environment in the phase of opening out and development of a deposit, environmental load caused by unit processes identified within this phase was calculated. Numerical data characterising these processes are presented in **Table 3**. Values of eco-indicators of the processes were calculated by multiplying the quantity characterising a given process by the value of an eco-indicator 99 corresponding to computational unit of the process (see Table 1). Total load was calculated by summing up values of eco-indicators calculated for individual unit processes identified in this phase of colliery's operation. Calculated quantities in the three categories of losses were presented in Table 3.

The model colliery in the phase of opening out and development of a deposit causes the total load expressed in points of the eco-indicator 99 which amounts to 5.7 MEw. In the 'human health' category a 22.9-per-cent loss takes place, in the 'quality of ecosystem' category a 4.8-per-cent loss and in the 'resourses' category a 72.9-per-cent loss. The greatest losses in individual categories are caused by following processes:

- The 'human health' category – entry driving by means of explosives (497.3 kEw),
- The 'quality of ecosystem' category – shaft sinking (102.5 kEw),
- The 'resources' category – entry driving by means of explosives (3.8 kEw).

Table 3: The eco-indicator of the model mine in the phase of opening out and development of a deposit

No	Identified unit processes	Unit	Quantity	Eco-indicator in individual categories [Ew]			Eco-indicator [Ew]
				Human health	Quality of ecosystem	Resources	
1.	Shaft sinking	m^3 of driven shafts	12 950	395 752	102 564	285 547	783 863
2.	Drivage by means of blasting	m^3 of headings	429 000	497 640	102 960	3 196 050	3 796 650
3.	Drivage by means of a heading machine	m^3 of headings	286 000	400 400	62 920	634 920	1 098 240
4.	Longwall face installation	m^3 of starting faces	13 000	13 520	3 250	8 970	25 740
Total environmental load				1 307 312	271 694	4 125 487	5 704 493

Table 4: Eco-indicator of the model mine in the phase of extraction of a deposit

No	Identified unit processes	Unit	Quantity	Eco-indicator in individual categories [Ew]			Eco-indicator [Ew]
				Human health	Quality of ecosystem	Resources	
1.	Drivage by means of explosives	m^3 of headings	100 100	116 116	24 024	745 745	885 885
2.	Drivage by means of a heading machine	m^3 of headings	42 900	60 060	9 438	95 238	164 736
3.	Getting the body of coal	Mg of gotten	2 500 000	15 00 000	75 000	20 450 000	22 025 000
4.	Longwall face installation	m^3 of starting faces	10 400	10 816	2 600	7 176	20 592
5.	Longwall equipment dismantling	m^3 of longwalls	7 800	546	312	936	1794
6.	Closing down workings by filling	$m^3$of workings	28 600	12 298	10 010	26 598	48 906
7.	Storage of industrial wastes in a working	$m^3$of workings	42 900	25	4	287	317
8.	Cleaning coal at a preparation plant	Mg of cleaned coal	2 500 000	250 000	25 000	350 000	625 000
9.	Storage of coal	Mg of coal	250 000	15 000	1 750	19 750	36 750
10.	Storage of wastes on the ground	Mg of stored wastes	500 000	31 500	4 000	41 000	76 500
11.	Storage-overhaul-and-repair activities	1 month	12	4 263	789	5 370	10 422
Total environmental load				2 000 624	152 927	21 742 100	23 895 902

5 Eco-indicator of the Model Mine in the Phase of Extraction of a Deposit

By means of the eco-indicator 99 methodology an eco-indicator of a mine in the phase of extraction was performed which constitutes an assessment of influences on the environment consistent with the standard ISO 14040. The method of estimating numerical values characterising individual unit processes identified in this phase of mining operation is analogical to the previous phase. The values of the eco-indicators for unit processes are shown in Table 1. Based on these data the environmental load in the three categories of losses were calculated for each process and for the whole model mine. The results are shown in **Table 4**.

The model mine in the phase of extraction of a deposit causes a total environmental load which expressed in points of the eco-indicator 99 amounts to 23.9 [MEw]. In the 'human health' category losses amount to 8.4 per cent, in the 'quality of ecosystem' 0.6 per cent and in the 'resourses' category 91 per cent.

The greatest losses in all categories are caused by the process of getting body of coal and the next greatest ones are:

- In the 'human health' category – cleaning coal at a preparation plant (250.0 kEw),
- In the 'quality of ecosystem' category – cleaning coal at a preparation plant (25.0 kEw),
- In the 'resources' category – entry driving by means of explosives (745.7 kEw).

Value of the eco-indicator 99 per 1 Mg (tonne) of coal extracted at the model mine amounts to 9.55 Ew.

6 Verification of the Model: The eco-indicator of a real colliery

On the basis of the eco-indicator methodology presented in previous chapters calculations of the value of the eco-indicator 99 were performed for a real working colliery. An inventory of characteristic quantities of individual unit processes connected with the extraction of 1.23 million tonnes of coal in 2001. The characteristic quantities and corresponding values of the eco-indicator 99 are presented in **Table 5**.

The analysed mine caused total environmental load of 11.14 MEw in 2001. In the 'human health' category losses amounted to 7.9 per cent, in the 'quality of eçosystem' category 0.5 per cent, and in the 'resources' category 91.6 per cent.

The greatest losses in all categories were caused by the process of getting body of coal which amounted to 10.8 MEw, and next the process of driving a heading by means of heading machine which amounted to 130.9 kEw.

The value of the eco-indicator 99 for 1 Mg (tonne) of coal extracted in 2001 at the analysed mine amounts to **9.06 Ew** and is lower than the value of the eco-indicator 99 calculated for the model mine (Ew = 9.55).

Table 5: The eco-indicator of the exemplary mine on the basis of data from 2001

No	Identified unit processes	Unit	Quantity	Eco-indicator in individual categories [Ew]			Eco-indicator [Ew]
				Human health	Quality of ecosystem	Resources	
1.	Drivage by means of explosives	m^3 of headings	5 389	6 251	1 293	40 148	47 692
2.	Drivage by means of heading machines	m^3 of headings	34 089	47 724	7 499	75 677	130 901
3.	Getting the body of coal	Mg of gotten	1 230 000	738 000	36 900	10 061 400	10 750 200
4.	Longwall face installation	m^3 of starting faces	10 613	11 037	2 653	7 323	20 907
5.	Longwall equipment dismantling	m^3 of longwall faces	1 440	100	57	172	316
6.	Closing down workings by filling	m^3 of workings	7 050	3 031	2 467	6 556	12 055
7.	Storage of industrial wastes in workings	Mg of stored wastes	52 299	836	104	9 989	10 878
8.	Cleaning coal at a preparation plant	Mg of cleaned coal	330 000	33 000	3 300	46 200	82 830
9.	Storage of coal	Mg of coal	166 000	9 960	1 162	13 114	24 402
10.	Storage of wastes on the ground	Mg of stored wastes	372 000	23 436	2 976	30 504	56 916
11.	Storage-overhaul-and-repair activities	1 month	12	4 263	789	5 370	10 422
Total environmental load				877 641	59 202	10 296 455	11 147 522

7 Conclusion

1. By means of the presented methodology it is possible to calculate environmental loads caused by individual unit processes with division into the basic categories of influence: human health, quality of ecosystem and natural resources.
2. The calculated values of the eco-indicators of the individual unit processes enable to make comparisons of environmental loads and eventual decision making on changes in the ecological policy of a mine.
3. On the basis of the inventory analysis performed at all mines it is possible to calculate the mean value of the eco-indicator 99 for each unit process. These indicators will be used to compare the value of environmental load of each similar process at any mine with the corresponding mean. (Multiplication of the mean of an eco-indicator 99 by the value of the quantity characterising a unit process).
4. By summing up the values of the eco-indicators of individual unit processes, it will be possible to gain the eco-indicator's value characterising the whole mine. In the model case the indicators can be calculated for the phase of opening out a deposit and for the phase of extraction.

8 Recommendation and Outlook

1. The presented LCA methodology can be used to compare the operation of individual mines in the aspect of their influence on the environment. If data of the same type with regard to unit processes are at disposal then mines can be ranked. It is possible to perform a simple and fast evaluation of each of the technological changes of the process of coal extraction on respect of its effects on the environmental. Based on the LCA's results it is possible to make capital decisions connected with modernisation of specific production processes.
2. The presented methodology can be used for any other production plant in which unit processes can be isolated and assessed.
3. In the further research, the effectiveness of the presented evaluation methods should be verified by means of another methodology (exp. EPS) .

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